May 1, 2000

Ms. Nancy A. Elizondo
U.S. Department of Energy
Idaho Operations Office
850 Energy Drive, MS 1221
Idaho Falls, ID 83401-1563

Dear Ms. Elizondo:

Attached is a topical report describing activities completed and/or nearing completion in the first phase on Project DE-FG07-99ID13780, "Investigation of Minimum Film Boiling Phenomena on Fuel Rods Under Blowdown Cooling Conditions ".

If you have any questions, please contact me by e-mail to bajorek@mne.ksu.edu, or by calling me at (785) 532-2607.

Very Truly Yours,

Stephen M. Bajorek
Kansas State University

Phase I Topical Report: DE-FG07-99ID13780, "Investigation of Minimum Film Boiling Phenomena on Fuel Rods Under Blowdown Cooling Conditions "

Introduction

The main objectives of "Investigation of Minimum Film Boiling Phenomena on Fuel Rods Under Blowdown Cooling Conditions " are to obtain minimum film boiling temperatures and heat transfer coefficients typical of the blowdown cooling period of a large break loss of coolant accident (LOCA) in the hot assembly of a light water reactor. Flow through the hot assembly during blow-down cooling is expected to be a post-CHF dispersed droplet flow at moderate pressure, 75 to approximately 400 psia (0.517 to 2.76 MPa). Segments of the hot assembly may quench, if sur-face temperatures drop below the minimum film boiling temperature. The minimum film boiling temperature is dependent on several parameters including flow rate, pressure, flow quality and the clad surface. Thus, the experimental goal of this investigation is to measure rod temperatures and determine surface temperatures and heat transfer coefficients for these prototypical blowdown conditions for rods with clad materials similar to actual fuel rods. The goal of the analytical part of this investigation is to develop a mechanistic model for the quench process in a blowdown cooling flow.

The objectives of the first phase of this investigation were intended to serve as initial milestones to be achieved on the way towards the overall program goals. These initial objectives are as follows: (a) acquire the main components for the experimental facility and perform the initial calibrations, (b) perform a materials feasibility for neutron radiography of blowdown cooling flows, and (c) develop and test the basic analytical model for blowdown quench. The following sections provide details and status of each area.

Experimental Facility

The experimental facility has been designed, and major components have been acquired. The basic facility is on schedule for completion and initial testing in late May 2000. The major components of the facility consist of a 23 kW DC power supply and electrically heated fuel rod simulators. Both the power and the fuel rod simulators were constructed by Stern Labs, Inc. The rods were designed to attain a maximum linear power of 7 kW/ft with a uniformly heated length of 24 inches (0.61 m). Rods with two types of cladding were obtained. Four rods were obtained with Inconel clad, and two with Zircalloy clad. Each rod is instrumented with three Type K thermo-couples and are capable of initial clad temperatures exceeding 1600 ^{o}F (1144 K). The thermo-couples in each rod have been calibrated.

"Shake-down" testing of the rods and power supply is being performed using a mock up of the final test section, but with the planned (high pressure) outer housing replaced with a Plexiglas housing. This allows a fuel rod simulator to connected to the power supply and heated in order to check the thermocouple and electrical measurements. The rod is submerged in subcooled water for these tests in order to prevent high temperatures and oxidation of the clad surface.

Final preparations for test set up and construction of the test section with a high pressure housing is in progress and is expected to be complete in late May. This section will make use of a high pressure steam supply system (purchased from KSU funds) and is designed to preserve a hydraulic diameter typical of a PWR rod bundle. Preparations for running high power tests have included the installation of two three-phase AC 100 amp electrical lines into the Thermal-Hydraulics Lab to run the steam supply and the DC power supply. A separate 100 amp line has also been installed in the TRIGA reactor bay to allow neutron radiography in the later stages of this investigation.

With design, component acquisition, construction, calibration testing nearing completion, the experimental facility objective is considered to be successfully met.

Neutron Radiography Study

The purpose of the “materials testing” during this phase of the investigation, was to determine the feasibility of using titanium as a housing material for neutron radiographic visualization of flow within the test section. Because of high temperatures involved in blowdown dispersed droplet flows, a housing material such as aluminum would not be acceptable. Titanium was considered an alternative, because of its high melting temperature and low cross section for thermal neutrons.

To investigate the use of titanium as a housing material, the thermal neutron port of the KSU TRIGA reactor was used to radiograph a titanium tube that was partial filled with water. The tube radiographed had a 0.75 inch (0.01905 m) diameter, which is the same size as that to be used in the experimental facility. The tube thickness was 1.0 mm, which again is the appropriate size for the final test section. The radiograph proved to be successful. The commercial grade titanium did not absorb significantly and water within the tube was clearly visualized. (The titanium did not activate, and thus will not pose a radiological hazard.) The radiograph used a low reactor power of 10 kW for an exposure time of 600 seconds. Calculations show that good contrast should also be obtained with a moderate reactor pulse.

Analytical Model

A “microscale” model of the blowdown quench process is also being developed as part of this investigation. The model simulates droplet motion within a boundary layer, and calculates heat transfer to the droplet and heat transfer to the steam. The objective of Phase I work was to have a preliminary model operable. This objective was successfully completed. The model is functional and performs the intended calculations. Calculations have been performed for Reynolds numbers from 10^3 to 10^4 and void fractions from 0.95 to 0.9999, which is approximate range of conditions for blowdown cooling. Work in later Phases of this project will enhance and refine the model by adding/replacing models for conduction at the clad surface, thermal radiation, and droplet evaporation.